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INVESTIGATION OF THE VARIATIONS OF COSMIC RAY INTENSITY AND OF CORPUSCULAR FLUX PROPERTIES DURING THE MAGNETIC STORM IN JULY 1958

(Issledovaniye variatsiy intensivnosti kosmicheskikh luchey i svoystv korpuskulyarnogo potoka vo vremya magnitnoy buri v iyule 1958 g.)

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ABSTRACT

The effect of cosmic rays during the magnetic storm of July 1958 is being analyzed according to the data of numerous stations. The Forbush effect spectrum is found. The possible mechanism of polar aurorae at low latitudes is being examined. A cross section is made of the profile of the retarding part of the flux by way of reconstitution of cosmic ray intensity in neutron and hard components after the Forbush effect. The variation of the magnetic field in the flux is determined, just as are its extension and gradient. The direction of the field in the flux is determined by way of analysis of daily perturbed variations. A possible interpretation is given by the observed effects.

COVER-TO-COVER TRANSLATION

The profile of the Forbush effect, linked with the peculiarities of Earth's trapping by corpuscular streams and by electromagnetic properties of their fluxes, was investigated in a series of works [1, 2, 3]. In particular, work [1] studied also the Forbush effect, linked among other numerous storms, with that of July 1958.

[redacted]

This case presents a particular interest because of a sharply expressed rise observed prior the commencement of the Forbush effect, which, according to the interpretation in reference [3], is linked with cosmic ray reflection from the advanced magnetized front of the stream. However, the estimate of stream's elongation, and of the magnetic field intensity was made in reference [3] according to data from a small number of stations. It is of interest to define these estimates more accurately using the material of the world station network, and also to attempt to appraise the character of the field's variation in the stream.

1. SOLAR ACTIVITY, GEOMAGNETIC FIELD, AURORAE, IONOSPHERE

The active region of the Sun, reponsible for the magnetic storm of 8 July 1958, was situated within the limits of 10° to 50° Northern latitude. The heliolatitude of the Earth was at that time 4° N. This region crossed the central meridian (CM) of the Sun from 4 to 13 July. A chromospheric flare of the 3+ class was observed near the CM on 7 July from 00 27 to 04 35 hours. It was accompanied by a type IV radioburst of the class 3. A very major storm began on 8 July at 07 48 hours UT, and ended on 10 July at 11 00 hours.*) The active period took place on 8 July from 08 00 to 24 00 hours. This storm had a sudden commencement.

An intense aurora was observed during the night from 8 to 9 July between 16 00 and 20 30 hours in the 30 to 35° latitude range.

A negative perturbation with a sharply expressed sudden commencement began at 16 00 hours in the ionosphere. At 17 00 hours a total absorption occurred, which then was replaced by a total shielding of the F-region by the E_s-layer.

2. DATA ON COSMIC RAYS

In order to investigate the effect of the magnetic storm thirty-six instrument data, corrected for pressure, and disposed

*) Time is UT unless stated otherwise

at various locations of the terrestrial globe have been utilized. Among them must be mentioned 28 neutron monitors (N), 5 ionization chambers (I), and 3 cubic telescopes (T). The list of stations, their coordinates, and the values of the geomagnetic field are compiled in Table 1.

A sharp decrease in intensity of cosmic rays' neutron component began on 8 July at 09 00 hours, and 2 to 3 hours later that of the hard component. This decrease lasted 8 hours, after which the intensity remained constant during 30 hours, and began the intensity increase that lasted 66 hours.

TABLE 1

Stations	Type of device	Φ	λ	Hardness BeV/s	Altitude above sea level	
London	T	49,0°	09°E	3,5	y. m.	sea level
Wellington	N	54,3	0W	2,4	»	
Resolute Bay.	»	45,4	175E	3,3	»	
NORIKURA	»	82,9	95W	1,0	»	
TOKYO	I	25,6	138E	9,7	2840	meters
	»	25,5	140E	9,8	y. m.	sea level
GALE	»	54,4	12E	2,3	»	
BERKLEY	»	52,3	12E	2,6	»	
DEEP RIVER	N	44,1	122W	4,3	»	
KAMPALA	»	56,2	78W	1,35	»	
LEEDS	»	—2,0	32E	14,5	»	
ALMA-ATA	»	56,6	02W	2,1		
LINCOLN	»	33,0	76E	6,0	806	
MOSCOW	»	33,7	19E	5,0	y. m.	sea level
	»	50,8	97W	2,25	350	
GETTINGEN	»	52,0	38E	2,6	y. m.	sea level
RIO DE JANEIRO	»	53,5	00E	2,5	»	
Churchill	»	52,3	10E	2,6	273	
Sulphur	»	12,7	43W	11,6	y. m.	sea level
Ottawa	»	69,7	94W	1,05	»	
	»	58,2	116W	1,4	2283	
Norchian Bay.	»	56,8	76W	1,5	y. m.	sea level
Upsala	»	0,6	75W	14,4	3400	
CHICAGO	»	72,2	18E	1,05	y. m	sea level
	»	58,6	18E	1,5	»	
COLLEGE	»	52,6	88W	1,9	»	
Ushuaia	»	21,3	158W	11,3	»	
	N	64,8	32W	0,5	»	
Zugspitze	»	—43,2	68W	6,1	y. m.	sea level
CLIMAX	»	—73,1	63E	1,2	»	
MOSCOW	»	48,2	11E	3,5	2960	
MÜNICH	»	48,1	106W	3,0	3400	sea level
IRKUTSK	T	52,0	38E	2,6	y. m.	
JUNGFRAU	N	48,6	11E	3,4	»	
	»	40,8	104E	5,2	»	
	»	49,7	07E	3,2	3400	

The general course of the intensity is shown in Fig.1, on the following data are brought forth : a — average data for the 4 ionization chambers ; σ — average data for 21 neutron monitors. The shape of the curve a indicates that the intensity remained constant during 36 hours, while the time of regeneration lasted only nearly 40 hours. In the neutron component, the intensity continued to slowly diminish during 26 hours after an initial fast drop, and then it reached the initial level 86 houts afterwards.

3. MAGNETIC FIELD IN THE STREAM

Utilized the data enumerated, one may determine certain properties of the corpuscular flux, having generated the observed effects in cosmic rays. If according to [1] we designate by $t_{\sigma c}$ the time of the fast drop, by t_1 the time of the small decrease, by t_{nc} the time, when the cosmic ray intensity was constant, and by t_2 the time of regeneration, we may determine, on condition of accounting for the fact that the tangential component of the corpuscular flux' velocity $u_t = 4 \cdot 10^7$ cm/sec, the shortest distance from the Earth to the edge of the stream, when the intensity was minimum. It appears from fig.1 that $t_1 = t_2 = 86$ hours, whence $l_1 = l_2 = 4 \cdot 10^7$, $t_1 = 1.24 \cdot 10^{13}$cm.

The relation between the effects in the neutron and the hard components is $\frac{\delta N}{N} / \frac{\delta I}{I} = 3$, and with the help of the graphs from reference [1] we find that $\varepsilon_{min} = 80$ BeV and $f = 0.1$. Knowing ε_{min} and l_1, we shall calculate the mean intensity of the stream's magnetic field

$$H_1 = \frac{\varepsilon \, min/2}{300 \, l_1} = 1.1 \cdot 10^{-5} \text{ gauss.}$$

Since $H_1 l_1 = H_2 l_2$, and $l_1 = l_2$, we have $H_1 = H_2$, i.e. in the given case the field in the stream is symmetrical relatively to the line of least intensity. These results agree well with those obtained in reference [1], within the limits of the accuracy of estimates.

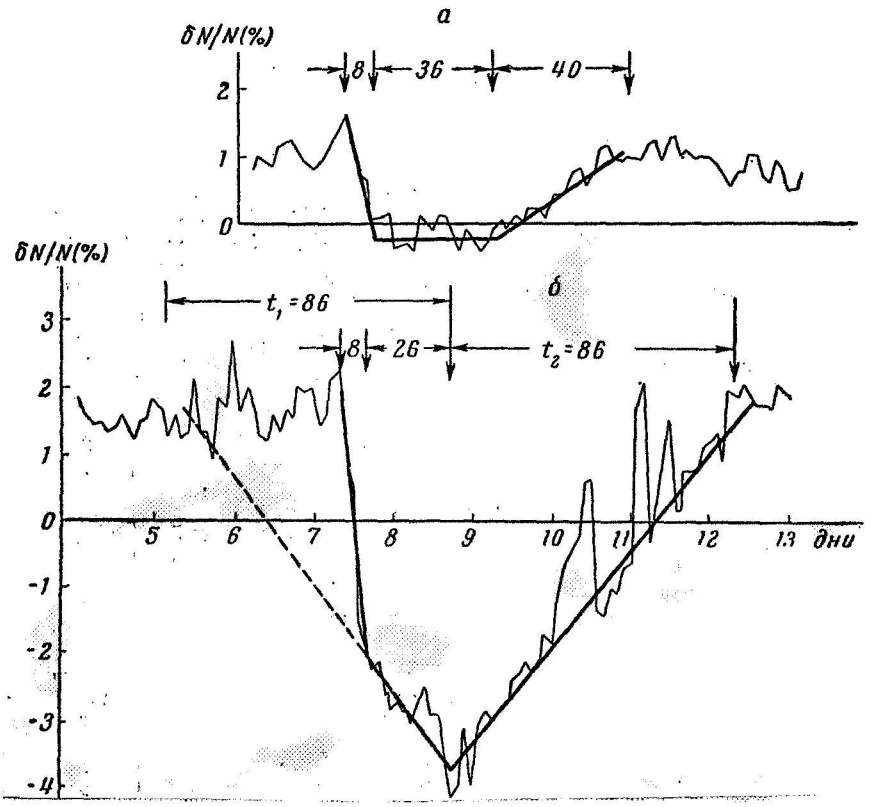

Fig. 1

Effecting the cross section of the regeneration profile of cosmic ray intensity's hard and neutron components at various points of the Earth's being in the stream, i.e. at various instants, let us compute the variation spectrum and the distance from the Earth to the lagging edge of the stream. In this way, we thus shall find the magnetic field variation across the stream. Since the decrease in cosmic ray intensity is determined by the product $H_x x$, where x is the shortest distance to the stream's edge, and H_x is the mean value of the field along the elongation from the edge of the stream to the distance x, where the Earth is situated at the given moment, we have

$$\bar{x} \int_0 H(x)\,dx. \qquad (1)$$

Here H(x) is the distribution of the field in the stream.

Differentiating the expression (1) along x, we shall find

$$H(x) = \frac{d}{dx}(xH_x), \qquad (2)$$

Hence, the field's gradient in the stream will be :

$$\frac{dH(x)}{dx} = 2\frac{dH_x}{dx} + x\frac{d^2H_x}{dx^2}. \qquad (3)$$

The results of computations of $dH(x)/dx$ for various instants of time are shown in Table 2.

JULY. 1958 DAYS	Time HOURS	$\frac{\delta I}{I}$, %	$\frac{\delta N}{N}$, %	$\frac{\delta N}{N} / \frac{\delta I}{I}$	ϵ_{min}, Бэв	H_x, γ	$\frac{dH(x)}{dx} \cdot 10^{-12}$ γ/см
10	10	0,2	1,1	5,5	50	0,67	
10	20	0,5	1,7	3,4	70	0,94	0,33
11	06	0,9	2,2	2,44	98	1,3	0,05
11	16	1,2	2,8	2,33	104	1,4	0,14

As the last column's data indicate, the field is nonuniform in the stream, and the rate of its variation is different in various parts of the stream. Its maximum value equals 1.4 γ, but near the edges it is 2.5 times lower. During the time of fast drop the neutron intensity dropped by 3.7 percent. Hence, the distance from the spot in the stream, where the breakdown occurred in cosmic ray intensity decrease, to the forward front of the stream is

$$S = t_1 3.7/5.5 = 8.3 \cdot 10^{12} \text{ cm}.$$

Taking into account that the fast decrease took place over 8 hours, we shall determine the flow velocity of the stream's leading edge

$$u = \frac{S}{t_{6c}} = 2.88 \cdot 10^8 \text{ cm/sec}$$

On the other hand, the commencement of the Forbush effect relatively to the solar f are was delayed hours, whence the mean flow velocity of the stream is

$$u = 1.34 \cdot 10^8 \text{ cm/sec}$$

Consequently, the degree of compression of the forward part of the stream is $u_\phi / u = 2.15$, and the mean magnetic field in it must be 2.15 times greater. In the center of the stream's leading edge the field must reach an intensity of the order of $10\,\gamma$.

Knowing the intensity of the magnetic field frozen in the stream, let us determined the mean density of the flux [1]. Since $H_1 = H_2$, we also have

$$\rho_1 = \rho_2 = \frac{H^2}{4\pi v^2} = 500\ см^{-3}.$$

In the forward part of the stream

$$\rho_\phi = \rho_1 \frac{u_\phi}{u} = 1075\ см^{-3}.$$

When the steam approaches the Earth, it compresses the Earth's magnetic field, which thus must increase by the magnitude

$$\Delta H_3 = \frac{H_{сж}}{3v} \sqrt{u_\phi u} = 560\,\gamma.$$

This value agrees well with the experimentally observed amplitude of the sudden rise in geomagnetic field intensity — nearly $670\,\gamma$ in the H-component according to observations in Voeykovo, near Leningrad.

Taking account of the Earth's magnetic field accretion in the course of the magnetic storm's initial phase, let us determine the distance from the center of the Earth to the leading edge of the stream:

$$Z = R_3 \sqrt[3]{\frac{0{,}33\ zc}{\Delta H zc}} \Big/ 2 = 1{,}83\, R_3.$$

Consequently, during the magnetic storm period the advanced front (leading edge) of the stream was situated at the distance of 5300 km from the surface of the Earth. The magnetic lines of force passing over the equator at such a height, intersect the Earth at points of $\pm 35^\circ$ geomagnetic latitude. The particles of the corpuscular flux, hitting these magnetic lines of force, may reach along them the

upper atmosphere layers. This is precisely the cause of aurorae at such low latitudes. Generally speaking, another possibility is not excluded. It consists in a possible intense particle outflow from the radiation belt along the magnetic lines of force during the disturbance of the Earth's magnetic field by the corpuscular streams.

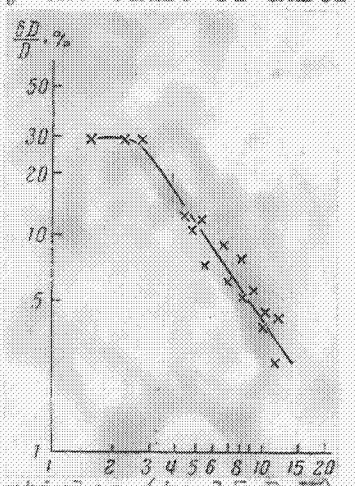

Fig. 2

4. ENERGY SPECTRUM OF THE FORBUSH EFFECT

The primary energy spectrum of particles (to 15 BeV), subject to the influence of the magnetic storm, calculated by the geomagnetic effect account being taken of coupling factors for the maximum of solar activity [4], is indicated in Figure 2.

The spectrum is described by the expression of the form

$$\frac{\delta D(\varepsilon)}{D(\varepsilon)} \simeq -\begin{cases} \text{const}, & \text{if } \varepsilon \lesssim 3 \text{ Bev} \\ a\,\varepsilon^{-1,3\pm0,2}, & \text{if } 3 \text{ BeV} \leqslant \varepsilon \leqslant 15 \text{ Bev}. \end{cases}$$

The lower boundary of the spectrum is the energy threshold of the "plato" latitude dependence of the effect, i.e. $\sim$ 3 BeV (Fig. 3)

Experimental and theoretical values expected of effect relations of the neutron and hard components are compiled in Table 3.

T A B L E 3

Stations and component relations	Effect relations		Stations and component relations	Effect relations	
	exper. values	anticip. value		exper. values	anticip. value
Norikura N/I	2.13	2.16	Chicago N/I	2.99	2.9
London N/I	4.02	3.95	Galle N/T	2.07	2.12
	1.07	1.02			

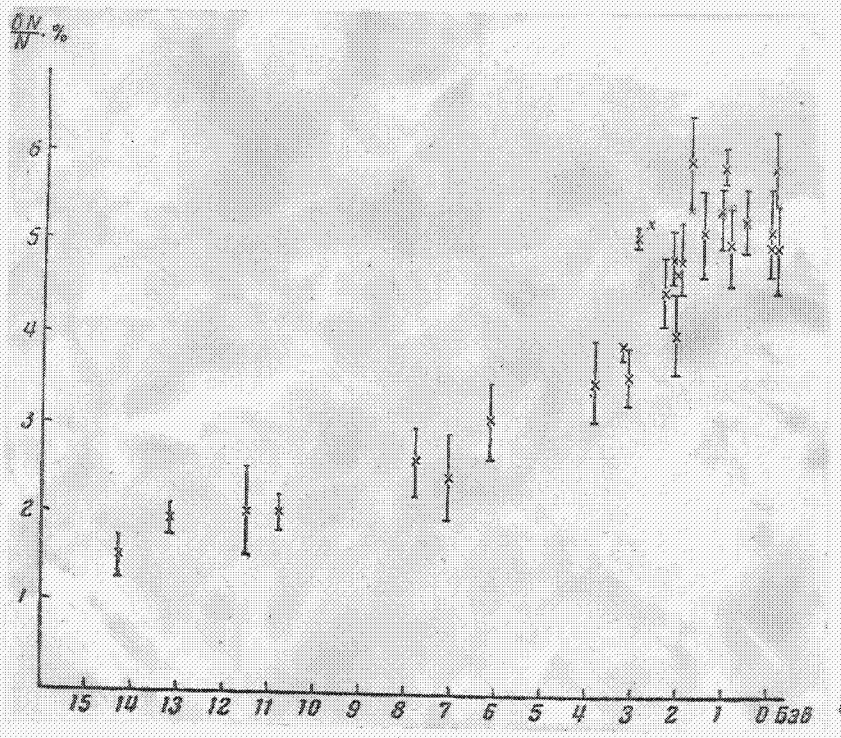

Fig. 3

5. PERTURBED DIURNAL AND SEMI-DIURNAL VARIATIONS

Analysis of diurnal and semi-diurnal variations according to three-day data prior to Forbush effect, and three afterwards, averaged by five devices installed in the southern hemisphere, and 20 — in the northern hemisphere, has established that the complementary diurnal variation is particularly evident in the southern hemisphere, and it diminishes somewhat in the northern hemisphere. It must be pointed out that in the given case one may only refer to the tendency to increase or decrease of the diurnal variation. The semi-diurnal variation during the storm apparently increases in both hemispheres. The amplitude of the diurnal and semi-diurnal variations are compiled in Table 4, hereafter:

Hemisph.	Prior to Forbush eff. amplitude %		After the Forbush effect amplitude %	
	1st harmon.	2nd harmonic	1st harmon.	2nd harmonic
South.	0,49±0,07	0,27±0,05	0,53±0,07	0,33±0,05
North	0,56±0,03	0,24±0,02	0,52±0,03	0,34±0,02

The time of the maximum of the first harmonic is shifted toward morning hours at all stations, that of the second harmonic toward the evening hours at thirteen stations, and toward morning at the remaining stations. Fig. 4 shows the first harmonic of the diurnal variations for certain stations, according to data prior and during the storm (data related to the perturbed period are circled).

As may be seen from Fig. 4, the perturbed amplitudes of the first and second harmonics are identical in both hemispheres. Hence it follows, that the field of the stream is normal to the ecliptic plane, and because the time of the maximum of the first harmonic shifts to morning hours, the direction of the field in the stream is the same as that of the Earth's field [5].

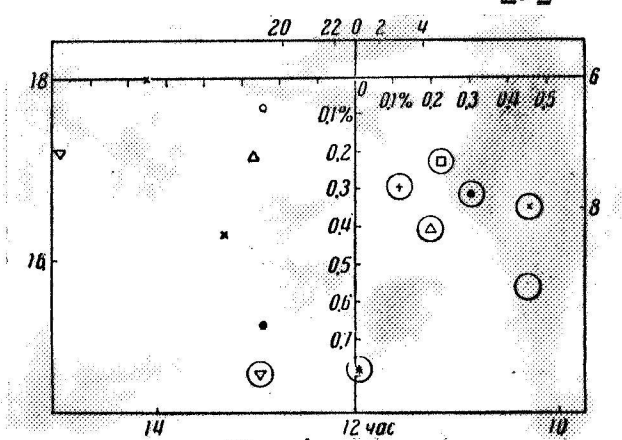

Fig. 4

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Translated by ANDRE L. BRICHANT
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Washington D. C. 8 January 1961

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